

Table 5

Extreme Bounds and Uncertainty Measures for the
 Coefficient of Mean Sulfates (MEANS) in a
 Simultaneous Equation System Involving 2 Focus
 and 12 Doubtful Variables

Standard error (Sample Sigma) of MEANS = 5.6387

Data Confidence	0.0	.250	.500	.750	.950	.990	1.000
Upper Bound	14.5	32.6	35.2	38.0	42.2	45.3	72.0
Lower Bound	14.5	-2.47	-4.98	-7.62	-11.7	-14.6	-37.3
Specification Uncertainty	-	35.07	40.18	45.62	53.9	59.9	109.3
Contract Curve	14.5	19.0	19.5	20.0	20.7	21.3	19.7
Posterior t Value	2.51	3.97	4.17	4.39	4.73	4.99	11.8
Prior Sigma (σ_o)	∞	8.41	7.59	6.87	5.97	5.40	0.0

Sampling Uncertainty of MEANS = 22.49

reciprocity between medical care and health status has been a frequent target for critics of earlier work,^{10/} they choose to estimate by two-stage least squares a linear system in which physicians per capita and mortality incidence are endogenous. Because of the absence of data on alcohol consumption in two areas, they reduce the sample size from the 104 metropolitan areas of Table 2 to 102 areas. The structural expression that they estimate (their regression number 6-5) includes all the right-hand-side variables of Table 1, plus per capita smoking expenditures, per capita alcohol expenditures, and the endogenous variable, patient care physicians per 10,000 people. We fully concur in their conclusion (p. 365) that: "Neither the addition of a medical care variable ... nor the use of a simultaneous equation framework has much effect on the estimated air pollution coefficients." Table 5 reports the results for MEANS of an application of the SEARCH procedure to the Chappie and Lave (1982) simultaneous system. MEANS and physicians per capita are focus variables. A comparison of this table with our Table 2 makes evident the basis of our agreement. Table 5 provides no reason whatsoever to alter the conclusions we earlier drew from Table 2.^{11/}

V. CONCLUSIONS

In this paper, we have examined the role that the priors of investigators have played in air pollution aggregate epidemiology. We find that the Chappie and Lave (1982) results are overwhelmingly dominated by what appear to be arbitrary priors for variables of uncertain meaning. Further, the specification uncertainties in the models they examine are substantial relative to the sampling uncertainties of their data.

One can conclude that a prior which says that %65+ contributes positively to mortality incidence is supported by Chappie and Lave's (1982) aggregate epidemiology data. The data also support a prior belief that %>4YRCOLL and mortality incidence are negatively associated, although the magnitude of this association is unclear. However, other prior beliefs receive little or no support from this data set. This includes the prior which asserts a positive association between air pollution and mortality incidence. The evidence that one can glean for the absence of a positive association is no more compelling. In short, the aggregate epidemiology data set that Chappie and Lave (1982) employ is noninformative about the association between air pollution and mortality incidence. That is, when we consider the entire set of plausible models, the corresponding range of inferences becomes too large to be useful.

REFERENCES

- 1/ See, for example: Koshal and Koshal (1973); McDonald and Schwing (1973); Mendelsohn and Orcutt (1979); and Lipfert (1980). This does not exhaust the list.
- 2/ Gerking and Schulze (1981), 229.
- 3/ Gerking and Schulze (1981), 233.
- 4/ The nontraumatic mortality rate excludes ICDA Codes 000-999, that is, accidents, homicides, suicides, and other external causes.
- 5/ Lave and Seskin (1973, p. 286) are explicit about the hypothesis search technique they employed. They arrived at their "best" model in the following way:
"Variables whose coefficients were greater than their standard error were retained and the others were eliminated, subject to two qualifications. Since interest centered on the air pollution variables, at least one was retained from each set.... Sometimes the retained air pollution variable still contributed nothing to the statistical significance of the regression. Such variables were eliminated, subject to the restriction that at least one air pollution variable was retained in the final equation."
As Atkinson and Crocker (1982) note, this pre-test approach in which numerous variables are "tried on" and only the "final" or "best" results are reported fails to minimize mean squared error or other reasonable loss function criteria. The tradeoff the researcher makes between increases in bias due to incorrect priors and reductions in variance is unclear.
- 6/ Sargent (1981) provides an interesting guide to searching for models that uncover causes as opposed to searching for models that best fit the data.
- 7/ As are all the Lave-Seskin type studies, the "raw" data used by Page and Fellner (1978) are measures of central tendency taken over metropolitan areas. In effect, their techniques therefore form indices of indices.
- 8/ See Leamer (1978), Cooley and LeRoy (1981), and Leamer and Leonard (1981). The latter expository paper is quite thorough while also being very accessible. Leamer (1983) presents a rather whimsical treatment. Dhrymes (1982) gives a critical commentary on the overall philosophy of the method. Leamer (1982) admits that the method retains some opportunity for the investigator to disguise his priors. Roberts (1974) and Thiel (1961) are early treatments of ideal criteria for reporting scientific results.
- 9/ In the simple bivariate case, an isoprobability ellipse is the contour in 2-space representing all combinations of the variables which have

identical probability.

- 10/ See, for example, Gerking and Schulze (1981), and Freeman (1982).
- 11/ An application of SEARCH to the endogenous physicians per capita variable in the structural expression for mortality incidence revealed specification uncertainties of .627, 1.07, and 1.98 respectively at data confidence levels of .250, .990, and 1.000. The sampling uncertainty for the endogenous physicians per capita variable is .647. The simultaneous system thus appears to pay a price in increased variance for a questionable gain in reduced bias.

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The Health Effects of Air Pollution: A Reanalysis¹

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Using a newly assembled data base, we explore the relationship between mortality and measures of sulfates and suspended particulates in 96 cities, counties, and metropolitan areas (SMSAs) of the United States. The data fit the previously estimated Lave-Seskin model and we cannot reject the null hypothesis of identical air-pollution coefficients in 1960, 1969, and 1974 cross sections. A strong, consistent, and statistically significant association between sulfates and mortality persists. The association is changed little by adding variables for smoking and alcohol consumption, by using a generalized least-squares estimator instead of OLS, by using city or county instead of SMSA data, or by adding medical care and nutrition variables and using a simultaneous equation framework. These results can be used to support stringent abatement of sulfur-oxides air pollution.

public. Air pollution is not a single chemical but rather a conglomeration of thousands of different substances present in the atmosphere. Identifying those harmful to humans and quantifying the dose-response relationships are not easy tasks. We summarize one set of studies of the health effects of sulfur oxides and present new analyses in an attempt to deal with criticisms and to explore the extent to which previous analyses can be replicated.

Severe health effects result from short-term exposure to high levels of air pollution, such as those occurring during the London fog episode of 1952, which resulted in about 4000 excess deaths and large increases in the prevalence of respiratory disease (Goldsmith and Friberg [7], Lave and Seskin [10], EPA [29]). The health effects of the much lower levels of air pollution currently prevailing in urban areas are more difficult to determine.

The past decade has seen a series of epidemiological studies undertaken to shed light on the association between air pollution and health; the work of Lave and Seskin [10-14] has served as one focal point. They used multiple-regression analysis to estimate the effect of air pollution (primarily sulfates and suspended-particulate matter) on mortality rates across more than 100 U.S. metropolitan areas during the 1960s. Their work relied on published data, usually collected for other purposes, that provide only a crude characterization of the "true" variables of interest. Nevertheless, Lave and Seskin [10] found a consistent, statistically significant effect and estimated that reductions in air-pollution levels from stationary sources associated with the EPA's current standards would result in a 7.0% reduction in total mortality and morbidity levels. They placed a dollar value of \$16.1 billion (1973 dollars) on these improvements and concluded that they were cost effective.

Criticisms of the Lave and Seskin work fall under five general headings.

(1) Aggregate analysis of poor data provides little or no information about the effects of air pollution. (2) The estimated models omit important variables (e.g., cigarette smoking and diet) or use crude surrogates (Gerking and Schulze [6], National Academy of Sciences [19]). (3) Estimation methods make inefficient use of the information contained in the data (e.g., using ordinary least squares when heteroscedasticity might be suspected). (4) The models fail to treat explicitly the "aggregation problem" arising from the use of data on cities or SMSAs rather than individuals (Lipfert [15, 16]). (5) The models may be misspecified by not considering inherent simultaneous relationships, making interpretation of estimated coefficients difficult or even meaningless (Crocker *et al.* [5], Gerking and Schulze [6]). We shall investigate selected aspects of these criticisms using a new data base. In Sections II and III we explore the first criticism while replicating the original Lave-Seskin specification and presenting a slight revision of the basic model; the next four criticisms are examined in Sections IV-VII; our conclusions are presented in Section VIII.

During 1981 the Environmental Protection Agency (EPA) was required to review and revise its sulfur-oxide standards. Many attacks on those standards have been mounted, most claiming they are too stringent and not required to protect public health (Holland *et al.* [9], N. Y. Academy of Medicine [4]). In the 1970 Clean Air Act Amendments, Congress instructed the EPA to set primary air-quality standards that would protect the health of even the most sensitive members of the public. The resulting standards have been a focus of controversy within the scientific community as well as among the

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II. INTERPRETING AGGREGATE AIR POLLUTION-MORTALITY RELATIONSHIPS

Ideally, one would relate various levels of both dose and dose rate of air pollutants to measures of health status for homogeneous individuals. If other factors were controlled experimentally or statistically, the air pollution-health relationship could be interpreted as a cause and effect relationship. In nonexperimental situations, it is impossible to control for all other relevant factors; measures of both air-pollution dose and health are notoriously inadequate. Even in the most carefully controlled clinical study, past exposure to air pollution is unmeasured or characterized crudely, current exposure levels provide little detail on the myriad specific pollutants, and there is genetic heterogeneity and vast differences in personal habits influencing health.

While no study of the long-term relationship between air pollution and health in humans could be perfect, the use of data aggregated over geographical areas is particularly suspect. Diverse individuals are being lumped together with only crude measures of their diversity; air-pollution data characterizing ambient air quality are far from adequate for calculating individual exposures. Yet such studies have a number of advantages. (1) They are relatively quick and cheap to carry out since they use existing data. (2) They represent a vast array of conditions that reflect the current and past environments in which people live. (3) They reflect, albeit vaguely, the experience of tens of millions of people. Over time, the first advantage becomes less important and the second somewhat less so; however, there is always too little research money and low cost is indeed an advantage. As a practical matter, such studies are the only tool for observing large numbers of people and environments in less than "real time."

At worst, this technique isolates a persistent, widespread association between air pollution and mortality.² Such an association is the building block of science since it calls for the construction of theories to explain it as a causal or spurious relationship and for empirical studies to contradict or corroborate the association.

We examine some empirical studies that appear to contradict the association between air pollution and mortality. We also attempt to investigate some of the theoretical criticism of this work. As a starting point, we reestimate the Lave-Seskin model using previously unavailable 1974 data for 104 Standard Metropolitan Statistical Areas (SMSAs).³ These results are presented in Table 1, along with the 1960 and 1969 results from Lave and Seskin [10] for comparison.

TABLE 1
Replication of the Lave-Seskin Model

	Regulation number	1-1	1-2 ^a	1-3 ^b
Dep	1974 TMR	1960 TMR	1969 TMR	
RSQ	0.861	0.831	0.817	
N	104	117	112	
Constant	313.342	343.230	387.011	
		2.87	3.36	
Air-pollution variables				
Min S	0.294	4.733	-0.384	
Mean S	0.04	1.67	-0.07	
Max S	16.915	1.726	6.329	
Sum S Elas	3.09	0.53	1.81	
Min P	-1.809	0.279	-0.527	
Sum P Elas	-2.09	0.25	-0.67	
Mean P	1.32	0.50	0.59	
Max P	2.366	0.199	0.434	
Sum P Elas	1.32	0.32	0.69	
Socioeconomic variables				
% > 65	-1.386	0.303	0.055	
% Nonwhite	-1.51	0.71	0.13	
% Poor	0.294	-0.018	0.130	
Density	1.80	-0.19	1.83	
Log Popn	0.06	0.44	0.56	
		-2.80	-1.38	
			-2.22	

Note. Numbers beneath the regression coefficients are *t* statistics. The sums of elasticities represent the estimated percent change in the dependent variable resulting from a 10% change in the three air-pollution variables.

^aRegression 1-2 is Lave and Seskin [10, p. 31] Regression 3.1-1.
^bRegression 1-3 is Lave and Seskin [10, p. 121] Regression 7.1-3.

²The original 1960 model was replicated for a number of data sets in Lave and Seskin [10].
³The data for New England areas are for State Economic Arcas rather than SMSAs. The "1974" air pollution and mortality data are averages over the 3-yr period from 1973 to 1975.

The dependent variable in each regression is the unadjusted total mortality rate TMR of the SMSA.⁴ The air-pollution variables are the smallest, arithmetic mean, and largest 24-hr readings of sulfates (Min S, Mean S, and Max S) and of total suspended particulates (Min P, Mean P, and Max P) averaged across all monitoring sites in the SMSA that met the EPA's publication criteria for at least one year. Socioeconomic variables include the percentage of persons 65 years and older (age), percentage of nonwhites (race), percentage of families with incomes below the poverty level (poor), population density (density), and the logarithm of SMSA population (size). Data sources and the means and standard deviations of all variables used are reported in the Appendixes.

The 1974 results are qualitatively similar to those for 1960 and 1969. Age is the most important variable and the other socioeconomic variables are generally statistically significant (*t* test at 0.05 level). The six air-pollution variables as a group make a significant contribution to regression 1-1; the *F* statistic is 7.61 (6, 92 dof). In contrast to the original Lave-Seskin results, however, the particulate variables are not significant (*t* tests on individual variables or an *F* test on their joint contribution). The sums of the three sulfate and three particulate elasticities⁵ are also reported as our "best" estimate of their net joint effects. The hypothesis that coefficients are similar across years does not appear to be correct, but collinearity among the air-pollution variables means that individual coefficients cannot be estimated with confidence or precision, as demonstrated by the negative or large positive estimates.⁶ A stringent test of this model is to ask if the estimated coefficients from the different data sets are identical, save for random variation.

The null hypothesis of identical coefficients in the two (or more) cross-sectional data sets can be examined with an *F* test by estimating the specification for the separate and pooled data sets. Lave and Seskin [10] could not reject the null hypothesis for the pooled 1960 and 1969 data sets. Similarly, when each year is allowed to have its own intercept, for both 1960

and 1974 and 1969 and 1974, we cannot reject the null hypothesis that the air-pollution and socioeconomic coefficients are identical.⁷

III. ALTERNATE SPECIFICATIONS OF THE BASIC MODEL

Other investigators have used somewhat different variables or functional forms (Lipfert [15, 16], Crocker *et al.* [5], Gerking and Schuze [6], McDonald and Schwing [17], Mendelsohn and Orcutt [18]); there is no strong theoretical justification or consensus for a particular model specification. Some of these results are inconsistent with those of Lave and Seskin [10], implying that the air-pollution coefficients might be quite sensitive to the precise model specification. To investigate this question, we estimated many variants of the basic Lave-Seskin model, first looking at the choice of air-pollution variables, then at the choice of socioeconomic variables, and finally at the choice of the dependent variable. A summary of this investigation is reported in Table 2.

Regression 2-1 (originally 1-1) reproduces the basic 1974 model with six air-pollution variables for comparison; regression 2-2 estimates the Lave-Seskin model with only two pollution variables (Min S and Mean P). Regression 2-3 is identical to 2-2 except that Mean S is used instead of Min S. The mean level of a pollutant characterizes cumulative exposure and may be a more appropriate measure for assessing "long-term" health effects. Indeed, Lave and Seskin [10, p. 122] remark that Mean S was preferred to Min S in their two air-pollution variable model for 1969. As further support for this specification, addition of the other four pollution variables to Min S and Mean P is still significant, but the addition of the four Min and Max values to Mean S and Mean P is not; the respective *F* values are 2.81 (4, 92 dof) and 2.47 (4, 92 dof).

Regression 2-4 examines an alternate set of socioeconomic variables. Population density is replaced by its logarithm (log density) since one would not expect a linear effect to prevail over a range as broad as 22 to 12,444 persons per square mile. Percent poor is replaced by median family income (income) because the latter has somewhat greater partial correlation with total mortality. These changes and other perturbations of the Lave-Seskin

⁴Lave and Seskin [10] found that the air-pollution coefficients were insensitive to whether the depended variable was adjusted directly or whether demographic variables were added as explanatory variables; thus, the unavailability of detailed 1974 demographic data for calculating age-sex-race adjusted mortality rates is not crucial.

⁵The elasticity (about the mean) of the *i*th variable is defined as $P * B_i(\bar{X}/\bar{Y}_i)$ and represents the percent change in the dependent variable (at its mean) that would result from a $P\%$ change in the explanatory variable (at its mean). Elasticities reported in this paper are scaled to represent the effect of a 10% change.

⁶The use of three separate measures of "sulfates" or "particulates" instead of just one stems from our lack of knowledge about the precise shape of the dose-response curves and the poor quality of the aerometric data.

⁷The standard procedure of allowing unique intercepts for each year is especially important here for two reasons. The geographical boundaries used for the 1960 and 1969 cross sections were the 1960 SMSA definitions in contrast to the 1970 definitions used for the 1974 cross section. In addition, the mortality rate fell sharply between the 1969 and 1974 data sets. For 1960 and 1974, $F = 1.30$ (11, 197 dof) and for 1969 and 1974, $F = 0.96$ (11, 192 dof). The null hypothesis cannot be rejected when the data set is restricted to SMSAs common to both years or when the coefficients of the socioeconomic variables are allowed to vary and the air-pollution coefficients alone are tested.

TABLE 2
Variations of the Lave-Seskin Model

	Regulation number						
	2-1	2-2	2-3	2-4	2-5	2-6	2-7
Dep RSQ	0.861	0.844	0.846	0.862	TMR	Natl MR	Natl MR
N	104	104	104	104	104	104	104
Constant	313.342	291.505	322.635	472.304	528.819	379.205	429.542
Air pollution variables							
Min S	0.294	18.322	-4.975	-3.043	-3.489	-1.768	
Mean S	0.04	5.40	-0.84	-0.57	-0.62	-0.34	
Max S	16.915	10.547	19.459	13.866	19.995	15.013	
Min P	3.09	5.55	3.78	2.87	5/4.98	3.22	
Max P	-1.809	-2.204	-1.774	-2.230	-2.230	-1.847	
Sum S Elas	-2.09	0.72	1.17	-2.65	-2.34	-2.82	-2.52
Min P	1.32	1.32	1.27	1.27	0.86	1.51	1.11
Mean P	2.366	2.366	2.111	1.234	2.283	1.502	
Max P	1.32	1.37	1.14	0.73	1.29	0.92	
Sum P Elas	-1.386	0.434	0.098	-1.278	-1.008	-1.450	-1.209
Mean P	-1.51	1.37	0.30	-1.37	-1.19	-1.63	-1.47
Max P	0.294	0.80	0.244	0.191	0.263	0.215	
Sum P Elas	0.06	0.37	0.08	-0.02	-0.12	-0.10	-0.19
Socioeconomic variables							
% > 65	64.265	66.182	66.022	62.770	58.417	63.056	59.179
	17.59	18.10	18.17	16.45	16.27	17.33	17.04
% Nonwhite	2.000	2.656	2.633	2.141	2.412	1.247	1.488
% Poor	1.96	2.67	2.67	2.59	3.21	1.58	2.05
Income	5.148	4.258	4.093	1.69			
Density	2.15	1.74		-0.020	-9.318E - 03	-0.018	-8.042E - 03
Log Dens				-2.91	-1.39	-2.68	-1.24
Log Popn	-44.594	-40.413	-46.889	-34.975	18.813	36.228	31.144
	-2.80	-2.50	-2.91	-1.84	1.25	1.05	1.93
% Coll Grad					-26.236	-40.171	-32.388
					-1.51	-2.21	-1.93
					-10.092	-8.988	-4.20
					-4.56		

socioeconomic variables have little impact on the estimated air-pollution coefficients.

In regression 2-5, an education variable, the percentage of college graduates in the 25 and older population, is added to the model. Lave and Seskin did not include an education variable although other investigators (Lipfert [15, 16], Grossman [8], Newhouse and Friedlander [20], Auster *et al.* [2]) have found it important. Its addition to the model reduces the estimated air-pollution coefficients by about one third and causes the income, density, and size coefficients to lose significance. The extremely large magnitude of education per se; it may reflect the covariance among the socioeconomic variables or it may be a surrogate for all "occupational exposure" effects, including air pollution; this will be explored further in Section IV.

Regressions 2-6 and 2-7 are identical to 2-4 and 2-5 except that deaths due to accidents, suicides, homicides, and other external causes are excluded from the mortality rate. Such deaths constitute 3.5–14.2% of total deaths and are not expected to be systematically related to air pollution; the natural mortality rate (Natl MR) is the more relevant measure of health status. The results are generally similar, although the air-pollution coefficients are slightly greater in magnitude and significance when the natural mortality rate is used. These modifications to the original Lave-Seskin model will be used in the following sections.

IV. OMITTED OR POORLY MEASURED VARIABLES

If important variables have been omitted from the model altogether or are represented only by crude surrogates, the observed association between air pollution and mortality may be spurious. The estimated air-pollution coefficients will be unbiased only if omitted variables are uncorrelated with those included in the model; conventional tests of significance may also be inappropriate.

Perhaps the most important omitted or poorly measured variables, and at the same time the most difficult to obtain cross-sectional data on, are the "personal habits" of the population. The adverse effect of cigarette smoking on the health of smokers and nonsmokers exposed to "second-hand" tobacco smoke is well known. Excessive use of alcohol and drugs, poor nutrition, chronic stress, inadequate medical care, lack of exercise, and participation in high-risk activities are also relevant (Breslow and Enstrom [3]). Ideally, all of these factors should be controlled.

McDonald and Schwing [17] used a smoking index based on state-tax data adjusted for urban-rural location; it was significant and enhanced the partial correlation between air pollution and mortality. Lipfert [15] found a smoking index based on state-tax receipts and price differentials to be significant, although he did not adjust for urban-rural location. He found

an excess mortality of 3 to 9% (depending on the cause of death) attributable to air pollution but concluded that sulfates were the least harmful of seven pollutants studied (particulates, sulfur dioxide, iron, benzo(a)pyrene, benzene-soluble organics, and manganese, the most harmful).

Crocker *et al.* [5] included a smoking index and nutrition variables constructed from regional food consumption patterns and did not find a significant relationship between air pollution and total mortality. Gerking and Schulze [6], using the same data base, found a significant positive relationship between particulate matter and total mortality when using OLS to estimate a model similar to that of Lave and Seskin [10]. However, they obtained negative but nonsignificant⁸ air-pollution coefficients after adding smoking, nutrition, exposure to cold, and medical care variables and using 2SLS to estimate a two-equation model treating mortality and medical care as endogenous. Since these studies differed in many ways from the work of Lave and Seskin [10–14], it is difficult to attribute their conclusions to “omitted variables” or any other single factor.

The Effects of Smoking and Alcohol Consumption

The smoking variable to be introduced is the estimated per capita expenditures on tobacco products in each SMSA. The variable is based on the 1967 Census of Business Retail Merchandise Line Sales [23] and circumvents some of the problems with using state indices. It is not affected by differences in urban and rural smoking habits or by “casual” bootlegging across state lines within an SMSA. However, it is an average for the entire population of an area and cannot distinguish among nonsmokers, former smokers, light smokers, and heavy smokers. The measure of alcohol consumption is analogous.⁹ The smoking and alcohol-consumption variables are not correlated with the air-pollution variables; the highest sample correlation ($N = 102$) is 0.17 between smoking and Mean S.

Regressions 3-1 and 3-2 in Table 3 replicate our basic specifications with and without the college variable; regressions 3-3 and 3-4 add the smoking and alcohol-consumption variables. Their addition makes a significant contribution to each regression, as shown by F statistics of 5.95 (2, 88 dof)

⁸The alleged significance arises from a technical error in the computation of the sampling variances of the 2SLS coefficients. The program used by Gerking and Schulze [6] and by Crocker *et al.* [5] saved the fitted values from the reduced form equation and entered them as an ordinary explanatory variable in the “second-stage” equation. This technique gives the correct 2SLS coefficients but, using the fitted rather than the observed values of the endogenous variable in the computations, gives erroneous values for their sampling variances and t -statistics. Here, the correct values are approximately one-fifth of those reported by Gerking and Schulze [6], leaving median age as the only “significant” variable in the second-stage mortality equation.

⁹The Cedar Rapids, Iowa, and Gadsden, Ala. SMSAs have been deleted because the alcohol-consumption index could not be constructed.

and 7.91 (2, 87 dof), respectively. The sums of the particulate elasticities remain near zero and nonsignificant while the sums of the sulfate elasticities increase slightly. The socioeconomic coefficients are less stable. The income effect is reduced by nearly half when smoking and alcohol variables are entered and by nearly two-thirds when the college variable is added (the correlation between income and alcohol consumption is 0.61). The size effect is slightly reduced, while the age and race effects increase slightly. While controlling for tobacco and alcohol consumption is important in accounting for variations in mortality rates across areas, it is not important in estimating air-pollution effects. We will retain these variables in further analyses.

The Effects of Industry Mix and Occupation Mix

We now attempt to obtain a better understanding of what the college variable measures. Areas with high air-pollution levels have fewer college graduates (the sample correlations with Mean S and Mean P are -0.45 and -0.29 , respectively) and so the partial correlation of mortality and air pollution will be affected by including this variable. To explore the possibility that the college variable is a surrogate for occupational-exposure effects, we added sets of variables describing the industrial composition (industry mix) and employment composition (occupation mix) of each SMSA to our basic model. Industry mix includes the unemployment rate and the fractions of the civilian labor force employed in manufacturing (durable and non-durable goods); wholesale and retail trade; business, repair, and personal services; educational services; construction; and all other industries. Occupation mix includes the unemployment rate and the fractions of the civilian labor force employed as professional, technical and kindred workers, and managers and administrators, except farm; sales and clerical occupations; craftsmen, foremen, and kindred workers; and all other jobs. These represent separate partitionings of the labor force and each sums to 100%; thus, each coefficient is to be interpreted relative to the others in its group. These results are also presented in Table 3. The industry-mix variables make a significant contribution to both regressions 3-5 and 3-6 (the F statistics are 6.65 (6, 82 dof) and 2.65 (6, 81 dof, respectively) but the occupation-mix variables do so only when the college variable is not present; the F statistics for regressions 3-7 and 3-8 are 3.88 (4, 84 dof) and 0.33 (4, 83 dof). The air-pollution variables continue to make a significant contribution in all regressions, although the magnitude is somewhat reduced. The most striking change is that the magnitude and significance of the college variable are reduced nearly to zero when the industry-mix variables are added.

Thus, the college variable seems to characterize the industrial and occupational structure of an area. In particular, areas with large employment in

TABLE 3
The Effects of Smoking, Alcohol Use, Industry Mix, and Occupation Mix

	3-1	3-2	3-3	3-4	3-5	3-6	3-7	3-8	Regulation number
Air-pollution variables									
Min S	-4.204	-2.407	-3.706	-1.787	-0.174	-0.153	-3.707	-1.473	
Mean S	20.512	15.470	21.248	15.926	14.247	14.222	17.061	15.958	
Max S	4.13	3.27	4.39	3.53	3.16	3.10	3.60	3.44	
Sum S Elas	1.51	1.11	1.66	2.62	-2.50	-2.26	-2.24	-2.19	1.27
Min P	2.450	1.633	1.661	1.794	1.660	1.654	2.108	1.879	
Mean P	-1.481	-1.206	-1.848	-1.558	-1.240	-1.240	-1.670	-1.623	
Max P	0.264	0.210	0.342	0.285	0.225	0.225	0.290	0.287	
Sum P Elas	-0.64	1.64	1.41	2.17	2.01	1.56	1.55	1.90	1.92
% > 65	62.744	58.978	59.058	54.982	54.368	54.354	57.066	55.577	Socioeconomic variables
% Nonwhite	17.06	16.82	16.11	16.05	15.66	15.48	15.37	15.13	
% > 65	1.52	1.20	1.450	1.043	1.300	2.027	2.022	1.340	
Income	-0.017	-7.487E - 03	-0.029	-0.036	-0.024	-0.020	-0.020	-0.020	
Log Dens	35.387	30.879	36.824	32.352	26.091	37.810	37.482	-2.80	
Log Popn	-41.275	1.87	1.77	2.05	1.99	1.52	2.13	2.17	
Smoking	-2.22	-2.01	-2.90	-2.79	-2.90	-2.83	-2.83	-2.70	
Alcohol Use	8.987	1.177	1.192	1.424	1.421	1.421	1.062	1.080	
% Coll Grad	-8.987	2.89	3.25	3.40	3.27	2.42	2.53	-10.470	
Industry-mix and occupation-mix variables									
% Manufactur	6.540	6.494	6.864	6.864	6.864	3.253	0.68	0.68	
% Trade	-1.22	-1.18	-1.18	-1.22	-1.131	-1.122	1.63	1.53	
% Services	-4.848	-4.848	-4.848	-4.848	-4.848	-4.848	-1.63	-1.63	
% Education	-12.173	-12.083	-12.083	-12.173	-1.63	-1.63	-2.49	-2.20	
% Construc	-11.825	-11.730	-11.730	-11.825	-4.65	-3.25	-2.49	-2.49	
% Professi	-5.404	1.941	1.941	-5.404	-0.37	-0.36	-0.37	-0.37	
% Clerical	-2.47	0.51	0.51	-2.47	-2.008	-1.976	2.89	2.89	
% Craftsmen	-2.299E - 03	-0.844	-0.844	-2.299E - 03	-0.385	-0.385	0.77	0.77	

education and in business and personal services have lower mortality rates, *ceteris paribus*, than do those with large employment in manufacturing, construction, wholesale and retail trade, and all other industries. Areas with high unemployment have high mortality rates as well. Part of this occupational-exposure effect may be due to occupational or even residential exposure to air pollution; however, water pollution, occupational disease, and other factors associated with industrialization are likely to be important as well. (Fatal occupational accidents have been excluded from the natural mortality rate.) Without data on these other factors, we cannot positively identify that component that may be associated with air pollution. Estimates without college imply that nearly all of the occupational-exposure effects are attributable to air pollution, while those with college imply that occupational-exposure effects are captured by the college variable instead.

V. THE CHOICE OF ESTIMATION TECHNIQUE

In the standard regression model, the errors for each observations are assumed to be drawn from distributions with identical variances. If they are drawn from distributions with different variances, ordinary least-squares (OLS) coefficient estimates are unbiased but are inefficient and their conventionally computed standard errors are inappropriate. Generalized least squares (GLS) can correct for such heteroscedasticity by dividing each observation by the square root of its error variance. One standard model has sample variance proportional to the square root of sample size or, in this case, to the square root of area population. This gives the largest observation in our sample about 11 times the weight of the smallest. However, assuming a stationary Poisson process for mortality over a 3-yr period, the smallest SMSA in our sample would have a standard deviation of 41.8 deaths per 100,000. Since this is only about 7% of the lowest total mortality rate occurring in the sample, giving so much greater weight to the most heavily populated SMSAs may be unwarranted if they are unrepresentative or have large errors of observation due to their large geographic areas.¹⁰

In Table 4 we present our basic model specifications estimated with OLS (regressions 4-1 and 4-2) and with GLS weighted by the square root of population (regressions 4-3 and 4-4). The air-pollution variables make a significant contribution to the GLS regressions as well as the OLS regressions; the *F* values for regressions 4-3 and 4-4 are 6.08 (6, 88 dof) and 2.88 (6, 87 dof). The sums of the sulfate elasticities change little when GLS is used; the sums of the particulate elasticities become slightly negative, although their effect is never statistically significant. By comparison, the socioeconomic coefficients, especially density, size, smoking, and alcohol consumption are less stable than the air-pollution coefficients.

TABLE 4
Model Estimation with OLS and Generalized Least Squares (GLS)

	Regulation number			
	4-1 OLS	4-2 OLS	4-3 GLS	4-4 GLS
Dep RSQ	Natrl MR 0.889 102	Natrl MR 0.911 102	Natrl MR 0.860 102	Natrl MR 0.892 102
<i>N</i>	483.832	542.732	297.536	396.059
Constant	5.21	6.40	3.57	4.93
Air-pollution variables				
Min S	-3.706	-1.787	0.434	-0.104
Mean S	-0.68	-0.36	0.09	-0.02
Sum S Elas	21.248	15.926	20.110	15.662
Min P	4.39	3.53	4.62	3.78
Max S	-2.198	-1.775	-2.443	-2.043
Sum S Elas	-2.82	-2.50	-3.08	-2.77
Min P	1.66	1.25	1.62	1.19
Mean P	2.661	1.794	4.496E - 04	-0.033
Mean P	1.56	1.15	2.453E - 04	-0.02
Max P	-1.848	-1.558	-1.223	-1.339
Max P	-2.12	-1.97	-1.44	-1.71
Sum P Elas	0.342	0.285	0.279	0.265
Sum P Elas	2.17	2.01	1.70	1.75
Socioeconomic variables				
% ≥ 65	-0.17	-0.26	-0.42	-0.58
% Nonwhite	59.058	54.982	57.125	53.645
Income	16.11	16.05	17.00	16.74
Log Dens	1.043	1.300	1.681	1.537
Log Popn	1.37	1.89	2.21	2.19
Smoking	-0.029	-0.020	-0.024	-0.016
Alcohol Use	-4.02	-2.93	-3.64	-2.47
% Coll Grad	36.824	32.352	58.867	49.177
	2.05	1.99	3.40	3.06
	-52.142	-45.416	-26.994	-22.707
	-2.90	-2.79	-1.63	-1.49

¹⁰ Examination of the OLS residuals revealed no evidence of heteroscedasticity.

The use of GLS has little effect on the air-pollution coefficients. In the absence of strong theoretical reasons or observed heteroscedasticity in the data to justify the use of GLS, we prefer the OLS estimators.

TABLE 5
Model Estimation for SMSAs, Counties, and Cities

	Regulation number					
	5-1 OLS	5-2 OLS	5-3 OLS	5-4 OLS	5-5 OLS	5-6 OLS
Dep	TMR SMSAs	TMR SMSAs	TMR Counties	TMR Counties	TMR Cities	TMR Cities
RSQ	0.875	0.904	0.907	0.913	0.847	0.847
N	96	96	96	96	96	96
Constant	569,630	635,731	16,557	16,890	879,610	899,655
	5.71	7.13	1.57	1.64	3.75	3.72
Air-pollution variables						
Min S	-10.326	-7.801	-5.628	-4.327	-8.830	-8.958
	-1.70	-1.45	-0.86	-0.68	-0.79	-0.80
Mean S	25.850	18.751	19.798	16.062	26.912	26.719
	4.62	3.64	3.30	2.67	2.78	2.74
Max S	-2.787	-2.081	-2.030	-1.708	-3.665	-3.697
	-3.08	-2.57	-2.06	-1.77	-2.06	-2.06
Sum S Elas	1.57	1.11	1.25	1.01	1.17	1.14
Min P	2.341	1.501	1.645	1.186	-1.138	-1.176
	1.27	0.92	0.91	0.67	-0.43	-0.45
Mean P	-1.485	-1.133	-0.961	-0.872	-0.630	-0.649
	-1.57	-1.35	-0.99	-0.92	-0.45	-0.46
Max P	0.314	0.233	0.315	0.281	0.520	0.521
	1.81	1.52	1.71	1.57	1.93	1.93
Sum P Elas	0.02	-0.06	0.30	0.20	0.34	0.32
Socioeconomic variables						
% ≥ 65	58.852	53.914	67.983	66.885	75.967	75.572
	14.84	14.81	20.82	20.88	12.95	12.62
% Nonwhite	1.894	2.216	3.665	4.000	3.965	3.944
	2.34	3.08	5.05	5.58	3.57	3.53
Income	-0.031	-0.020	-0.013	-5.913E - 03	-0.034	-0.032
	-4.00	-2.81	-1.75	-0.74	-2.18	-2.01
Log Dens	9.429	6.440	-3.004	-7.099	-78.588	-80.953
	0.47	0.36	-0.17	-0.42	-1.65	-1.68
Log Popn	-43.102	-37.096	14.955	23.073	-88.990	-88.428
	-2.26	-2.20	0.90	1.40	-2.76	-2.73
Smoking	0.708	1.017	1.332	-5.792	4.538	-1.283
	0.58	0.95	1.00	-2.44	1.93	-0.38
Alcohol Use	1.349	1.355	0.646	1.414	1.303	4.469
	3.09	3.52	1.42	1.09	1.49	1.88
% Coll Grad	-10.220	0.591			1.273	
	-4.92	1.33			1.45	

¹¹Six areas (Atlanta, Ga., Huntington, W.V., Newport News, Va., Oxnard, Calif., San Bernardino, Calif., and Tulsa, Okla., have been deleted because air-pollution data was not available for any sites located in the central city or county. New York City, St. Louis (city), and Baltimore (city) have been used as counties as well as cities.

geographic unit¹²; the dependent variable is the unadjusted total mortality rate.

The six air-pollution variables make a significant contribution to all six regressions (the *F* statistics are 7.21 (6, 82 dof), 3.67 (6, 81 dof), 5.23 (6, 82 dof), 2.83 (6, 81 dof), 2.89 (6, 82 dof) and 2.68 (6, 81 dof), respectively). The sum of the sulfate elasticities is large, significant, and stable across specifications, especially those with the college variable included.¹³ The sum of the particulate elasticities is near zero for SMSAs and slightly positive for counties and cities; the effect is never significant. The socioeconomic coefficients are much less stable. In particular, the strong SMSA college effect is cut in half at the county level and completely disappears at the city level. The age and race effects are highly significant throughout; they are largest in magnitude for cities and smallest for SMSAs; the income effect is largest for SMSAs. The other coefficients are unstable.

Considerable multicollinearity is present in all three data sets. The variability of the socioeconomic coefficients across specifications means that the data vary across geographical units and that the three data sets give at least somewhat independent information. The relative stability of the sulfate effect induces confidence that its "true" effect is being measured. While the possibility of a spurious correlation due to some omitted factor can never be ruled out, the stability of the sulfate coefficients across the three areas provides still further evidence against the importance of "omitted variables."

In contrast to Lipfert, we find a significant effect of sulfate pollution on mortality at the city and county level, as well as at the SMSA level. Particulates do not make a significant contribution to any of the regressions in the presence of sulfates¹⁴; their effect is slightly positive for cities and counties and near zero for SMSAs. As would be expected, the choice of geographic unit is unimportant in this context.

¹² Comparison of the data for SMSAs, counties, and cities reveals that the sulfate levels are almost identical for the three geographic areas. Particulate levels are lowest for SMSAs and highest for cities, although the differences are quite small. SMSAs have the youngest populations, fewest nonwhites, highest median incomes, largest populations, and lowest population densities. Cities have the oldest populations, most nonwhites, lowest incomes, fewest college graduates, smallest populations, and highest densities. Counties have the most college graduates. SMSAs have the lowest and most homogeneous mortality rates, while cities have the highest and least homogeneous mortality rates.

¹³ The Mean *S* elasticities for SMSAs, counties, and cities, are nearly identical in the specification with college and only two air-pollution variables; their values are 7.92, 7.42, and 7.77 respectively. (Those of Mean *P* are -0.01, 2.82, and 5.14.)

¹⁴ In results not reported, Mean *P* alone and all three particulate variables do make a significant contribution to SMSA, county, and city regressions when no sulfate variables are included.

VII. THE EFFECTS OF MEDICAL CARE AND NUTRITION—A SIMULTANEOUS EQUATION FRAMEWORK

Crocker *et al.* [5] and Gerking and Schulze [6] argue that a single-equation model is not adequate since medical care may affect health status while the extent of illness may affect the supply of medical care. When an explanatory variable is simultaneously determined with the dependent variable, a single-equation model produces biased and inconsistent coefficient estimates; a simultaneous equation framework can provide consistent estimates.

These objections cannot be dismissed lightly since Crocker *et al.* [5] did not find a significant association between air pollution and total mortality using such a framework, albeit with an incompletely specified model. Gerking and Schulze [6], using the same data base, obtained negative but nonsignificant¹⁵ coefficients with this framework although finding positive (but nonsignificant) coefficients when estimating the same model specification with OLS. Since this data base was restricted to just 60 of the largest U.S. cities, although not so constrained by data availability, the small sample size and multicollinearity among variables may have affected their conclusions.

To investigate the sensitivity of the air-pollution coefficients to the use of such a framework, we postulate the following simultaneous equation system:

$$\begin{aligned} \text{physician supply} &= f(\text{total mortality rate}, \text{size}, \text{income}, \text{college}, e) \\ \text{physician demand} &= g(\text{age}, \text{income}, \text{college}, \text{traumatic mortality} \\ &\quad \text{rate}, \text{birthrate}, u) \end{aligned}$$

$$\text{physician supply} = \text{Physician demand}$$

$$\begin{aligned} \text{mortality} &= h(\text{physicians per capita}, \text{air pollution}, \\ &\quad \text{age}, \text{race}, \text{income}, \text{density}, \text{size}, \\ &\quad \text{smoking}, \text{alcohol consumption}, v). \end{aligned}$$

This model is crude and does not reflect the complexity of the medical-care delivery system. A more realistic model of physician supply would, for example, take into account the hospital facilities and medical schools present in an area; presumably, they would attract physicians. A more realistic physician-demand model would include adequacy of medical insurance and access costs. The omission of relevant variables from a physician equation (and thus from the first stage ($X'X$)⁻¹ computation) should have little impact on the "second-stage" mortality equation; however, it does mean that we are using an instrumental variables estimator instead of

¹⁵ See Footnote 8.

the true two-stage least-squares estimator unless these variables are included in the mortality equation.

All of the coefficients in both physician equations should be positive; however, it is not clear what sign the physician coefficient in the mortality equation should have, as efficacious medical care can prolong lives but iatrogenic (e.g., physician-induced) disease can do the reverse (Wennberg *et al.* [33]). The expected signs on the other variables are unchanged.

Regressions 6-1 and 6-2 in Table 6 are the physician supply and demand equations; regressions 6-3 and 6-5 are the mortality equations estimated with OLS and with two-stage least squares, treating the physician variable as endogenous. Regression 6-4 is the reduced form mortality equation; regression 6-6 is the physician-supply equation estimated with two-stage least squares.

The physician supply and demand equations are not satisfactory. Median income has the "wrong" sign in both equations and birthrate has the "wrong" sign in the demand equation. Less than 50% of the variation in the dependent variable is explained in each case, indicating that important variables may have been omitted from the model; the OLS and 2SLS physician supply equations virtually identical.

The physician variable has a small but statistically significant and beneficial impact on total mortality. Comparison of regression 6-3 with regression 3-3 reveals that none of the other coefficients is much affected by the inclusion of the physician variable. The sum of the three sulfate elasticities decreases somewhat. The particulate coefficients change very little and remain nonsignificant. The use of the simultaneous equation framework has little impact on any of the coefficients except that of the physician variable. The estimated effect of medical care is more than twice that estimated in the OLS equations. There is a slight drop in the sulfate elasticities, while the effects of race, density, smoking, and alcohol consumption increase slightly. The sulfate elasticities are slightly higher in the 2SLS equation than in the reduced form equation, indicating that medical care might be able to ameliorate the effects of air pollution.¹⁶

Regressions 6-7, 6-8, and 6-9 add three nutrition variables analogous to those used by Crocker *et al.* [5] and Gerking and Schulze [6] to the OLS, reduced form, and 2SLS mortality equations (see Table 7). These variables

¹⁶The Durham, N.C., area, perhaps reflecting its role as a regional medical center serving people beyond its SMSA boundaries, was found to have nearly three times the number of physicians per capita of any other area. Both of the physician equations are affected by the removal of this "outlier." The college and income coefficients drop very sharply in both equations; the latter now has the expected sign in the demand equation. The only coefficient in the mortality equation greatly affected by the deletion of Durham is the physician coefficient, which increases by about 25% in the OLS model and nearly doubles in the simultaneous model.

are estimated protein, fat, and carbohydrate consumption in each SMSA; they are constructed from Department of Agriculture Household Food Consumption Survey data reported for four regions of the country and nine income groups and are at best a very crude measure of nutrition. They are not statistically significant, individually or jointly, in any of the three equations and have little impact on the estimated air-pollution coefficients.¹⁷

Neither the addition of medical care and nutrition variables nor the use of a simultaneous equation framework has much effect on the estimated air-pollution coefficients. We remain skeptical about the use of a simultaneous equation framework. Here, simultaneous determination doesn't appear to be important, so one is trading the minimum-variance property of OLS for a small improvement in consistency. In view of the large errors of observation and uncertainty about the correct model specification, we prefer the OLS estimators.

VIII. CONCLUSIONS

Using a newly assembled data base, we have explored the relationship between air pollution (sulfates and particulates) and mortality. The data fit the previously estimated model and we cannot reject the null hypothesis that the air-pollution coefficients are identical across 1960, 1969, and 1974 cross sections. A strong, consistent, and statistically significant association between sulfates and mortality persists. The association is changed little by adding variables for smoking and alcohol consumption, by using city or county instead of SMSA data, or by adding a medical-care variable and going to a simultaneous equation framework. We can thus reassure those who have expressed reservations about the earlier results of Lave and Seskin [10-14] that the association does not result from "omitted variables" giving rise to a spurious correlation between air pollution and mortality. Those who have found somewhat different results have often done so using less adequate data bases or methods.

¹⁷In results not reported, more comprehensive groups of variables representing eleven nutrients (protein, fat, carbohydrate, total calories, calcium, iron, vitamin A, thiamine, riboflavin, niacin, and vitamin C) and 14 food groups (milk, fats, flour, bakery products, meat, poultry and fish, eggs, sugar, potatoes, fresh vegetables, fresh fruits, canned vegetables and fruits, frozen vegetables and fruits, and vegetable and fruit juices) also failed to make a significant contribution to the OLS, reduced form, or 2SLS equations. Individual coefficients were occasionally "significant" although one can have little confidence in interpreting them because of serious multicollinearity among the variables and the crude nature of the data. The estimated effect attributed to sulfates decreased slightly when the eleven nutrient variables were added but increased slightly when the fourteen food-group variables were added. The sums of the three sulfate elasticities in the OLS, reduced form, and 2SLS equations are 1.16, 1.08, and 1.03 with the nutrient variables; 1.33, 1.16, and 1.27 with the food-group variables; and 1.02, and 1.13 with neither set of nutrition variables. The sulfate variables always remain statistically significant.

TABLE 6
The Effects of Medical Care and Nutrition - A Simultaneous Equation Framework

Dep	Phys/Cap	Supply	Demand	TMR	Reduced Form)	Supply	TMR	TMR	TMR
N	0.479	0.416	0.883	0.911	0.855	0.478	0.884	0.913	0.856
RSQ	-316.621	102	102	102	102	102	102	102	102
Constant	-4.03	0.53	5.88	5.61	4.89	-4.16	0.05	0.77	-0.01
Air-Pollution variables									
Min S	-3.952	-4.562	-1.205	-3.659	-4.427	-0.470	-0.07	-0.07	-0.470
Mean S	-0.70	-0.91	-0.19	-0.63	-0.86	-0.86	-0.07	-0.07	-0.470
Max S	3.74	3.24	2.51	19.156	16.077	15.015	2.53	2.53	-1.492
Sum SEIas	-1.914	-1.480	-1.476	14.948	18.868	18.868	-1.666	-1.666	-1.492
Min P	1.34	1.02	1.02	1.02	1.02	1.02	1.09	1.09	1.18
Mean P	1.07	1.52	2.423	0.446	1.992	1.992	0.602	0.602	0.602
Max P	-1.507	-1.746	-2.18	-0.94	-1.634	-1.634	-1.132	-1.132	-1.132
Sum PEIas	-2.37	-1.480	-1.372	3.68	3.36	3.36	-2.36	-2.36	-1.58
Min P	1.34	2.03	1.50	-1.980	-1.666	-1.666	1.10	1.10	0.29
Mean P	1.07	1.52	2.423	0.446	1.992	1.992	0.602	0.602	0.602
Max P	-1.507	-1.746	-2.18	-0.94	-1.634	-1.634	-1.132	-1.132	-1.132
Sum P EIas	-2.37	-1.480	-1.372	3.68	3.36	3.36	-2.36	-2.36	-1.58
Min S	1.34	1.02	1.02	1.02	1.02	1.02	1.09	1.09	1.18
Mean S	1.07	1.52	2.423	0.446	1.992	1.992	0.602	0.602	0.602
Max S	-1.507	-1.746	-2.18	-0.94	-1.634	-1.634	-1.132	-1.132	-1.132
Sum SEIas	-2.37	-1.480	-1.372	3.68	3.36	3.36	-2.36	-2.36	-1.58
Min P	1.34	2.03	1.50	-1.980	-1.666	-1.666	1.10	1.10	0.29
Mean P	1.07	1.52	2.423	0.446	1.992	1.992	0.602	0.602	0.602
Max P	-1.507	-1.746	-2.18	-0.94	-1.634	-1.634	-1.132	-1.132	-1.132
Sum P EIas	-2.37	-1.480	-1.372	3.68	3.36	3.36	-2.36	-2.36	-1.58
Socioeconomic variables	% <> 65	6.825	59.694	48.834	62.687	58.925	48.075	62.775	62.775
% Nonwhite	1.74	15.67	10.83	14.48	14.48	13.74	10.06	12.79	12.79
Income	-1.71	-1.59	2.90	1.415	3.255	3.255	1.06	1.69	1.69
Log Popn	24.650	2.07	-42.066	-42.233	24.289	-43.768	-43.823	-42.588	1.90
Smoking	1.657	1.054	-2.49	-2.06	2.04	-2.27	-2.49	-1.98	2.512
Alcohol Use	1.49	1.06	1.83	1.054	2.301	1.843	1.116	1.116	1.92
% Coll Grad	17.430	8.93	13.391	10.71	3.19	2.83	2.68	2.33	2.45
Protein									
Log Dens	29.220	28.943	39.665	29.771	28.860	41.977			
Nutrition variables									
Fat	0.19	0.19	0.20	6.952	-13.856	8.416			
Carbohydrate	0.18	0.18	0.16	-2.920	6.453	-2.222			
Medical-care variables									
AccSHomI	0.518	0.906	0.906	0.906	0.906	0.906	1.094	1.094	1.094
Birthrate	1.36	1.36	1.74	-8.119	1.119	-7.845	1.87	1.87	1.87
Phys/Cap	-6.197	-0.196	-0.196	-2.06	-2.11	-2.11	-0.197	-0.197	-0.197
TMR	0.219	0.21	0.21	0.238*	0.238*	0.238*	-0.641*	-0.641*	-0.641*

*Endogenous variable in two-stage least-squares equation.

The Effects of Additional Nutrition Variables									
Dep	TMR	TMR	(Reduced Form)	TMR	TMR	TMR	TMR	TMR	Regulation number
N	OLS	OLS	2SLS	OLS	OLS	OLS	OLS	OLS	7.6
RSD	0.907	0.930	0.886	0.902	0.930	0.885	0.930	0.885	102
Constant	-2.755E + 04	-2.287E + 04	-2.748E + 04	9245.343	6957.528	102	102	102	13091.558
Costanti	-2.77	-2.54	-2.50	1.36	1.39	1.99	1.39	1.39	1.99
Min S	-5.481	-7.143	-2.573	-8.008	-10.146	-4.475	-10.146	-8.008	3.78
Mean S	-0.98	-1.39	-0.41	-1.32	-1.85	-0.67	-1.32	-0.41	19.419
Max S	3.78	19.726	15.764	20.176	18.957	17.268	20.176	15.764	-0.41
Sum S Elas	1.16	1.08	1.03	2.12	2.15	1.55	2.12	1.03	-2.44
Min P	0.84	1.57	2.02	0.379	1.33	1.16	1.33	1.16	-1.140
Mean P	-1.140	-1.339	-0.751	1.22	2.35	0.913	1.22	0.751	-1.18
Max P	-1.18	-1.55	-0.70	-1.64	-2.69	-1.03	-1.64	-0.70	0.230
Sum P Elas	1.33	1.83	0.75	0.32	0.500	0.288	0.32	0.75	-0.284
% < 65	56.898	47.625	61.293	57.865	44.106	62.972	44.106	57.865	13.08
% Nonwhite	13.08	1.61	1.54	1.21	1.25	11.64	1.21	1.54	-30.071
Log Popn	1.08	1.05	1.03	1.18	1.99	1.54	1.18	1.99	-55.169
Log Dens	21.555	29.060	34.708	27.048	37.578	35.815	27.048	34.708	-446.974
Socioeconomic variables									
% > 65	56.898	47.625	61.293	57.865	44.106	62.972	44.106	57.865	13.08
% Nonwhite	13.08	1.61	1.54	1.21	1.25	11.64	1.21	1.54	-30.071
Log Popn	1.08	1.05	1.03	1.18	1.99	1.54	1.18	1.99	-55.169
Log Dens	21.555	29.060	34.708	27.048	37.578	35.815	27.048	34.708	-446.974
Nutrition variables									
Protein	53.239	145.565	-13.369	-0.07	-0.07	-0.07	-0.07	-0.07	0.30
Fat	-446.974	-397.250	0.87	-0.07	-0.07	-0.07	-0.07	-0.07	0.30
Carbohydrate	-84.848	-249.750	-44.968	-44.968	-44.968	-44.968	-44.968	-44.968	-244.600
Calories	36.566	31.054	-1.95	-1.89	-2.48	-2.48	-2.48	-2.48	-1.19
Choline	2.49	2.32	2.31	2.31	2.31	2.31	2.31	2.31	-1.27
Iron	48.625	-31.975	0.55	0.55	0.55	0.55	0.55	0.55	0.09
Vitamin A	0.187	0.166	0.269	0.269	0.269	0.269	0.269	0.269	0.187
Thiamine	-249.750	-254.022	-384.402	-384.402	-384.402	-384.402	-384.402	-384.402	-462.332
Niacin	535.045	167.808	667.080	667.080	667.080	667.080	667.080	667.080	-199.969
Vitamin C	1.36	0.44	1.53	1.53	1.53	1.53	1.53	1.53	-14.295
Milk	-1.54	-1.27	-1.02	-1.02	-1.02	-1.02	-1.02	-1.02	-1.54
Continued									

TABLE 7

The Effects of Additional Nutrition Variables

TABLE 7

While we have utilized somewhat improved measures of air pollution, many of the variables are still only crude surrogates for those desired. Ambient air quality readings, for example, represent only current exposure levels, do not take into account migration or other population movements, and do not reflect differences in indoor and outdoor pollution levels that would enable more accurate determination of actual population exposure. Physicians per capita, while perhaps a reasonable measure of the potential supply of medical care in an area, is hardly an adequate measure of its actual utilization. We emphasize the poor quality of the data to help explain inconsistent results that have been reported and to caution against the use of models that demand data of laboratory quality or confidence in the underlying theory. More careful causal modeling of the "true" factors affecting health and their interrelationships is also needed, preferably at the individual level.

Unlike Gerking and Schulze [6], we feel that such results are useful for estimating the health benefits of reductions in air-pollution levels and reiterate briefly their implications for policy analysis. Lave and Seskin [10, p. 218] estimated that 50% abatement of particulates and sulfates would lower the total mortality rate 4.7–5.9% if the estimated association is causal. Table 1 summarizes much of the previous work and adds new results; the comparable 1974, 1960, and 1969 sums of elasticities (from regressions 1-1, 1-2, and 1-3) are 6.9, 4.7, and 5.3%, with sulfates being even more important in 1974. When related to the EPA [30] estimate of abatement costs, these results support and strengthen the conclusions of Lave and Seskin [10] that stringent abatement of sulfur oxides and particulates would produce social benefits (based on health effects alone) greatly exceeding social costs. We regard the evidence for stringent abatement as compelling in spite of the occasional contrary results and unresolved theoretical questions.¹⁸

APPENDIX A: DEFINITIONS AND DATA SOURCES OF VARIABLES

	Mortality Rates (per 100,000 Population) [32]					
	TMR	Natl MR	Unadjusted total mortality rate (all causes of death)	"Nontraumatic" or natural mortality rate (all causes of death except accidents, homicides, suicides, other external causes; ICDA Codes 000–999)		
Flour	-1.409,412	-2224,928	-0.66	-1.55	-1592,866	
Baked Goods	-2519,659	-2807,360	-1.70	-1.26	-3334,272	
Meat	-2519,659	-2807,360	-366,478	-2.09	-1.64	
Poultry Fish	1492,979	1986,877	0.89	0.36	0.06	0.17
Eggs	1388,484	1988,931	0.89	0.37	0.90	0.66
Sugar	4697,100	4317,088	2.91	3.01	2.89	
Potatoes	26,932	248,543	0.03	0.03	0.29	
Fresh Veg	-814,460	-769,134	-814,460	-769,134	-474,900	
Fresh Fruit	20,914	20,914	-0.58	-0.64	0.13	
Can Veg Frt	-963,056	-788,662	-1.39	-1.32	-1.66	
Frz Vdg Frt	-1465,779	-1209,801	-1.10	-1.04	-1.28	
Vdg Frt Juice	2738,575	1685,712	1.35	0.95	2131,779	
AccsUHomi	1.895	1.493	1.895	1.493	1.28	
Medical-care equation variables	1.895	1.493	0.46	0.31	0.25	
Birthrate	3.03	2.43	445,903	334,046	300,802	
Phys/Cap	-0.172	-0.172	-0.567 ^a	-0.567 ^a	-1.16	
			-0.193	-0.193	-1.85	
			-1.297	-1.297	-2.76	
			-0.571 ^a	-0.571 ^a	-3.23	

^aEndogenous variable in two-stage least-squares equation

¹⁸The poor (though improved) quality of the air-pollution data preclude confident generalizations about the current standards of the EPA regarding particulates and sulfur dioxide. These results are based on total suspended particulates and total sulfates. Laboratory studies suggest that respirable particulates are more harmful to health than large particles and that acid sulfates are more harmful than sulfur dioxide. Thus, the results imply that abatement of particulates and (especially) sulfur oxides is warranted, but cannot support or refute current standards.

AccSuiHomi	"Traumatic" or nonnatural mortality rate (accidents, homicides, suicides; ICDA Codes E800-E978)	%Education	Percentage of civilian labor force in area employed in educational services industries
<i>Air-pollution Variables (Micrograms per Cubic Meter)¹⁹</i>			
Min S	Smallest 24-h sulfate reading	%Construct	Percentage of civilian labor force in area employed in construction industries
Mean S	Arithmetic mean of 24-h sulfate readings	%Profession	Percentage of civilian labor force in area employed in "professional" occupations (professional, technical, and kindred workers, and managers and administrators, except farm)
Max S	Largest 24-h sulfate reading	%Clerical	Percentage of civilian labor force in area employed in sales and clerical occupations
Min P	Smallest 24-h total suspended particulate reading	%Craftsmen	Percentage of civilian labor force in area employed in "craft" occupations (craftsmen, foremen, and kindred workers)
Mean P	Arithmetic mean of 24-h total suspended particulate readings		
Max P	Largest 24-h total suspended particulate reading		
<i>Socioeconomic Variables</i>			
%65+	Percentage of area population at least 65 years old ²⁰ [25]		
%Nonwhite	Percentage of nonwhites in area population [25]	Protein	Estimated total protein consumption
%Poor	Percentage of families in area with income below the poverty level [25]	Fat	Estimated total fat consumption
Income	Median income of families in area (dollars) [25]	Carbohydrate	Estimated total carbohydrate consumption
Density	Population density (per square mile) in area [26, 27]		
Log Dens	The logarithm of population density		
Total Popn	Total population in area ($\times 0.000001$) [27]		
Log Popn	The logarithm of total population		
%Coll Grad	Percentage of area population at least 25 years old that are college graduates [25]		
Smoking	Expenditures (per capita) on cigars, cigarettes, tobacco products in SMSA [23]		
Alcohol use	Expenditures (per capita) on alcoholic drinks and package alcoholic beverages in SMSA [23]		
<i>Industry-Mix and Occupation-Mix Variables [25]</i>			
%Unemployed	Percentage of civilian labor force in area unemployed	1974 ^a Dataset (N = 104)	1960 ^a Dataset (N = 117)
%Manufacturer	Percentage of civilian labor force in area employed in manufacturing (durable and nondurable goods) industries	1969 ^a Dataset (N = 112)	1974 ^b Dataset (N = 102)
%Trade	Percentage of civilian labor force in area employed in wholesale and retail trade industries	Mortality rates TMR	1974 ^c Dataset (N = 96)
%Services	Percentage of civilian labor force in area employed in services (business, repair, and personal) industries	Natl MR	1974 ^c Counties (N = 96)
		AccSuiHomi	1974 ^c Cities (N = 96)

APPENDIX B: MEANS AND STANDARD DEVIATIONS OF VARIABLES

Air pollution variables	—	—	—	—	—
Min S	3.425	4.724	3.463	3.425	3.451
Mean S	1.822	3.128	1.931	1.834	1.828
	9.636	9.965	10.937	9.646	9.585
	3.363	5.288	4.595	3.389	3.402

¹⁹Obtained on tape from U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle, N.C.

²⁰Unpublished 1974 estimates by county of the 65 and older population obtained from U.S. Department of Health, Education, and Welfare, National Clearinghouse on Aging, Washington, D.C.

	CHAPPIE AND LAVE					
Max S	27.317	22.839	27.329	27.442	27.119	27.417
Min P	13.299	12.441	14.628	13.366	13.217	13.359
Mean P	20.335	45.479	31.045	20.243	20.246	12.527
Mean P	6.288	18.571	13.550	6.315	6.385	22.350
Max P	75.016	118.145	95.580	74.846	74.528	7.823
Max P	20.570	40.942	28.642	20.736	20.292	79.121
Socioeconomic variables						
% ≥ 65	9.492	8.387	8.984	9.475	9.514	9.952
% Nonwhite	12.134	1.759	2.107	2.044	1.766	10.871
% Poor	9.393	9.806	10.410	12.695	12.222	12.230
Income	9859.000	—	—	10.264	9.841	9.883
Density	667.941	667.941	699.650	840.536	—	—
Log Dens	1339.141	1354.427	1377.749	—	—	—
Total Popn	0.909	0.427	—	—	2.581	2.592
Log Popn	1.434	5.722	0.811	0.977	0.429	0.423
% Coll Grad	0.417	0.417	11.461	0.399	0.925	0.939
Smoking	3.196	—	—	1.567	1.444	0.679
Alcohol use	—	—	—	1.390	1.482	0.679
Industry-mix and occupation mix variables						
% Unemployed	—	—	—	5.737	5.734	0.835
% Manufactur	—	—	—	0.407	0.411	0.418
% Trade	—	—	—	—	11.518	0.390
% Services	—	—	—	—	11.539	0.408
% Education	—	—	—	—	11.539	0.408
% Construct	—	—	—	—	11.664	0.408
% Profession	—	—	—	—	11.150	0.408
% Clerical	—	—	—	—	—	0.408
% Craftsmen	—	—	—	—	—	0.408

	1974 ^a	1960 ^a	1969 ^a	1974 ^b	1974 ^c	1974 ^c
Dataset	(N = 104)	(N = 117)	(N = 112)	Dataset	(N = 102)	SMSAs
						Counties
						Cities
						(N = 96) (N = 96) (N = 96) (N = 96)

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Industry-mix and occupation mix variables

% Trade	4.258	10.034
% Services	20.832	2.326
% Education	7.901	7.901
% Construct	1.955	8.092
% Profession	8.092	2.286
% Clerical	2.286	6.009
% Craftsmen	6.009	1.225
	1.225	23.993
	23.993	3.452
	3.452	26.454
	26.454	3.045
	3.045	14.082
	14.082	1.839

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